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**Performance Assessment of the OTTO Hurricane
with Invisio V60 and Sonic Defenders EP4**

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14. ABSTRACT Communication enhancement devices were designed for those who want to maintain natural hearing while protecting their ears from impulse and continuous noises like gunfire, explosions, vehicles, and machinery. There were potential advantages for this technology in military applications, provided an accurate and complete assessment of the performance had been obtained. The OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs were assessed for: continuous noise attenuation, sound localization, and speech intelligibility. The OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs caused degradation of localization capabilities in comparison to the open ear performance. The OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs in both open and closed filter conditions met the acceptable speech intelligibility scores ($\geq 80\%$ correct) in continuous noise levels of 65 and 85 dBA.					
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EXECUTIVE SUMMARY

Understanding the noise attenuation performance of a hearing protection device has been important in order to protect the user from excessive noise exposure and from over protection. Active electronic hearing protection devices have been designed to allow for enhanced communication and situational awareness, while at the same time protecting the auditory system from noise. It was important to measure the performance of hearing protection devices to gain objective and accurate assessments of the performance of the device and the effect/s on the auditory performance of the user. The objective of this study was to measure the performance of the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs for: continuous noise attenuation, sound localization, and speech intelligibility. The OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs caused degradation of localization capabilities in comparison to the open ear performance. Additionally, the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs performed in the acceptable range ($\geq 80\%$) for speech intelligibility performance at noise levels of 65 and 85 dB, but did not perform in the acceptable range at the level of 105 dB.

1.0 INTRODUCTION

Military personnel have been working in unpredictable noise environments, which require a more flexible type of hearing protection in order to complete a normal duty day while reducing the risk of permanent hearing loss. It was important to measure the performance of hearing protection devices to gain objective and accurate assessments of the performance of the device and the effect/s on the auditory performance of the user. A multifactorial assessment approach was used to adequately determine if currently available tactical hearing protectors met the military operation needs, including the following parameters: continuous noise attenuation, auditory localization, and speech intelligibility.

Continuous noise attenuation measurements characterized how much protection a hearing protection device (HPD) provided in an environment where the ambient noise levels were fairly stable (for example, riding in a HMMWV or a helicopter, or working in a machine shop). These measurements were conducted in accordance with American National Standards Institute (ANSI) standard S12.6-2008¹ Method A. Understanding the noise attenuation of a hearing protector was important in order to estimate the user's noise dose. Noise dose was calculated using the estimated level of noise under the hearing protector (using methods described in ANSI S12.68²) and the duration of time spent in that noise environment. Speech intelligibility measurements were conducted in accordance with ANSI S3.2-2009³ and were critical to understanding the communication performance for users wearing a hearing protection and communication device in multiple noise environments.

It has been found that wearing a hearing protection and communication device can degrade the user's ability to localize low-level sounds, which is essential to situation

awareness. Understanding these potential degradations would promote a more informed decision for those in charge of selecting hearing protection for the warfighter. A balance between providing adequate hearing protection for the expected noise environment and maintaining a level of situation awareness appropriate for the mission should be considered.

2.0 BACKGROUND

Military ground operations have been taking place in complex environments which necessitate creating balance between operational effectiveness and personnel safety. The goal of effectively protecting the hearing of personnel has been complicated by the need for warfighters to maintain access to acoustic cues in the ambient environment (Figure 1). Firing even a small number of rounds from a weapon has been known to cause temporary hearing loss, which therefore can produce the undesired result of impairing the ability to monitor the environment. Repeated unprotected exposures to small arms fire may generate these temporary changes and could eventually result in permanent hearing loss. Noise exposures from larger weapons and blasts could instantly cause permanent hearing loss if no protection is worn.



Figure 1. Special Operations Forces using Communication Devices in an Operational Environment

The objective of this study was to evaluate the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs for: continuous noise attenuation, auditory localization, and speech intelligibility.

The requirements associated with the military's use of tactical hearing protection and communication devices fueled the development of new performance metrics and measurement methods in order to best determine the impact of these devices on the mission⁴. Traditional passive earplugs and earmuffs have been found to impair the ability of an operator to localize sounds in the environment^{5,6}. A second metric was the number of front-back reversals of the target location that an individual demonstrated during the task. The third metric was a measure of reaction time, time to find a visual target, when sound was collocated with the visual target. The listener had to use the auditory localization information to locate the target and subsequently identify the target in this task. The reaction time was a salient measure of the quality of the localization cue⁷⁻¹¹.

AFRL conducted a series of measures to describe the performance of hearing protection and communication devices. The measures included passive continuous noise attenuation, impulsive noise insertion loss, input/output gain function, localization error with short duration (250 ms) and long duration (>1 sec) stimuli, reaction time from an aurally guided visual search task with distracters, and speech intelligibility.

3.0 METHODS AND RESULTS

The overall methods and results are described in the following sections. The first section describes the hearing protector that was used in the study. The second section describes how the device settings were configured for the evaluation. The subsequent sections describe each measurement method including a description of the subjects, the facilities, and the details of the specific measurement methods and results.

3.1 Hearing Protection and Communication Device

The Invisio V60 Tactical Headset System was a compact advanced communication system that was designed to allow users to connect, control and communicate across 4 separate channels at the same time. The V60 system was paired with the OTTO Hurricane dual in-ear headset (Figure 2), used with Sonic Defenders EP4 earplugs. The OTTO hurricane headset comes with an external boom microphone. The headset is equipped with a filter that can be opened in order to allow more low frequency sounds in for enhanced situation awareness and improved face-to-face communications while still providing high frequency attenuation. The sonic defenders EP4 earplugs come with a filter that was removed completely prior to testing with the OTTO hurricane.



Figure 2. OTTO Hurricane Headset (left) and Invisio V60 with OTTO Hurricane headset (right)

3.2 Continuous Noise Attenuation

Continuous noise attenuation performance measurements were collected with the device in the “passive” (electronics off) condition using human subjects. All human subjects were compensated volunteers. There were ten male and ten female subjects, ranging in age from 18 to 34 years. All subjects were required to have a computer administered screening audiogram via Hughson-Westlake method, with behavioral hearing thresholds inside the normal hearing range, which was 25 dB hearing level (HL) or better from 125 Hz to 8000 Hz.

The facility used for this portion of the study was specifically built for the measurement of the sound attenuation properties of passive hearing protection devices. The chamber (Figure 3), its instrumentation, and measurement procedures were in accordance with ANSI S12.6-2008.¹ This standard requires measuring the occluded and unoccluded hearing threshold of human subjects using a von Békésy tracking procedure. The thresholds were measured two times for the unoccluded ear condition and two times for the occluded ear condition (with device in place). The real-ear attenuation at threshold for each subject was computed at each octave frequency, 125 to 8000 Hz, by averaging the two trials (the difference between unoccluded and occluded ear hearing thresholds).

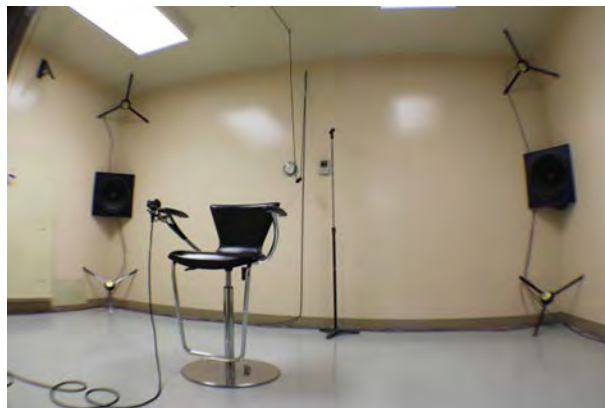


Figure 3. Facility used for measurement of continuous noise attenuation

Passive noise attenuation data were analyzed using the methods described in ANSI S12.68.² This ANSI standard detailed the methods for estimating the effective A-weighted SPL when hearing protectors are worn. The octave band method is the “gold standard” method for estimating a users’ noise exposure. This method requires both the noise spectra per octave band and the attenuation data per octave band. Mean and standard deviation (SD) noise attenuation data were calculated across subjects at each octave frequency band. A single Noise Reduction Rating (NRR) was also calculated for mean minus 1 and mean minus 2 standard deviations, Table 1. Figure 4 displays a graphical representation of the attenuation results at each measured frequency (mean minus 2 SD). There was a large difference in the performance in the low frequencies when comparing the open and closed filter noise attenuation results. At 125 Hz the difference was as large as 16 dB; the difference decreased as the frequencies increased with only a 1 dB difference at 8000 Hz.

Table 1. Passive noise attenuation data for OTTO Hurricane headset with Invisio V60 and Sonic Defenders EP4 earplugs, electronics off

Device		Frequency (Hz)							NRR	
		125	250	500	1000	2000	4000	8000	Mean-1SD	Mean-2SD
OTTO Hurricane/V60 w/ EP4 Filters Closed	Mean	24	23	22	24	29	28	30	20	15
	SD	5	4	5	3	4	7	4		
OTTO Hurricane/V60 w/ EP4 Filters Open	Mean	8	11	15	19	25	26	29	13	8
	SD	5	4	4	5	4	7	5		

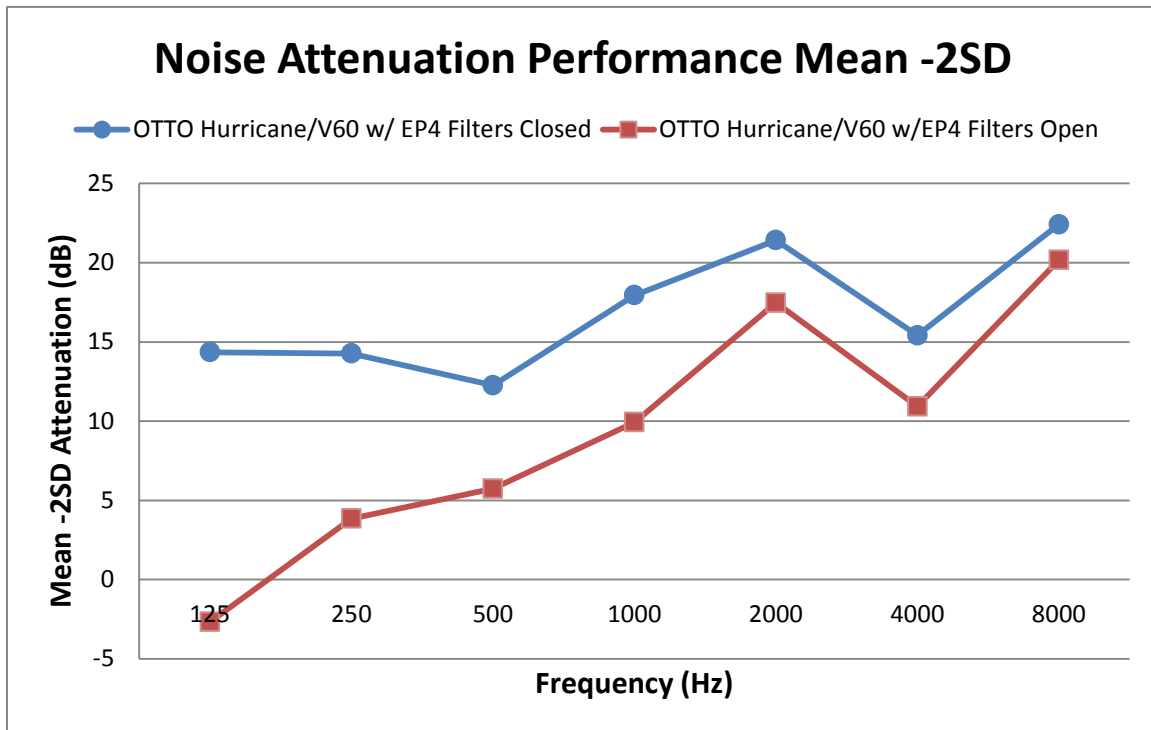


Figure 4. Passive mean -2SD noise attenuation for OTTO Hurricane headset with Invisio V60 and Sonic Defenders EP4 earplugs, electronics off

It is not always possible to calculate the effective A-weighted level under the hearing protector using the octave band method due to the lack of detailed noise data for all noise environments. Two other methods were described in ANSI S12.68: Noise Level Reduction Statistics, Graphical (NRS_G) and Noise Level Reduction Statistics for use with A-Weighting (NRS_A). NRS_G and NRS_A were calculated for the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs and displayed in Table 2 and Figures 5-8.

The NRS_G rating requires knowledge of both the C- and A-weighted noise levels, and uses this additional information about the noise spectrum to more precisely estimate the range of protection provided. For example, if the C-weighted noise was measured at 100 dB and the A-weighted noise was measured at 94 dB then the difference between the two weighting levels would be 6. Therefore, the range of protection provided by the hearing protector could be found in Figures 5 and 6 and/or Table 2 where B = 6. For the closed filter configuration, when the noise would be dominated by low frequency content (B = a

high number) the level of protection ranged from 19.5-26.6 dB. However, when the filter was open, the level of protection ranged from 6-13.4 dB. The results were more similar when comparing the open and closed filter configuration when very little low frequency content ($B =$ a low number) was expected. NRS_A is appropriate for unpredictable noise environments that may vary widely as is the case with many military operations. However, if one was considering a noise environment that was relatively constant (e.g., aircraft or other vehicles) then NRS_G should be used to calculate more accurate attenuation performance values.

Table 2. NRS_G results for OTTO Hurricane headset with Invisio V60 and Sonic Defenders EP4 earplugs, electronics off

Device		$B = L_C - L_A$			
		-1	2	6	13
OTTO Hurricane/V60 w/ EP4 Filters Closed	80%	23.8	21.2	19.9	19.5
	20%	29.5	26.8	26.2	26.6
OTTO Hurricane/V60 w/ EP4 Filters Open	80%	19.1	14.3	11.0	6.0
	20%	25.8	20.0	16.6	13.4

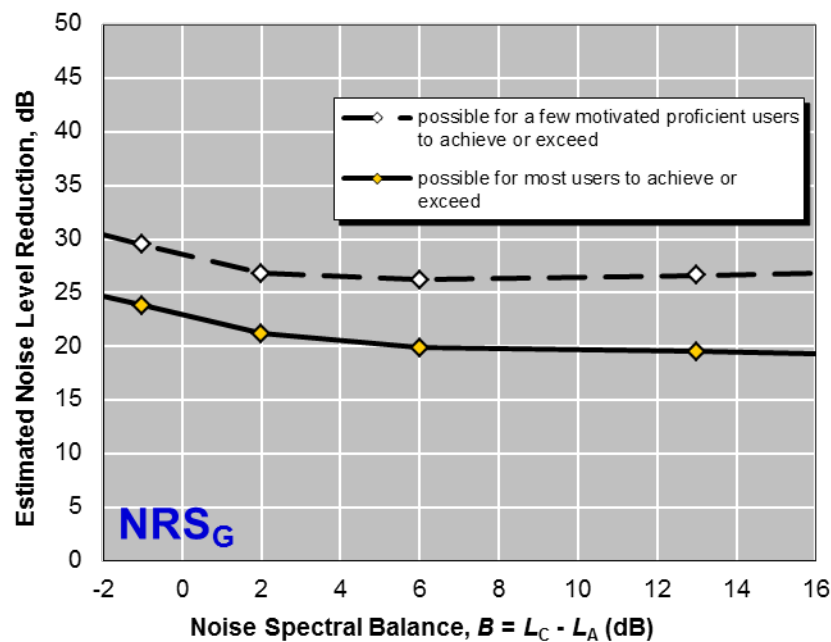


Figure 5. NRS_G results for OTTO Hurricane headset with Invisio V60 and Sonic Defenders EP4 earplugs, electronics off filters CLOSED

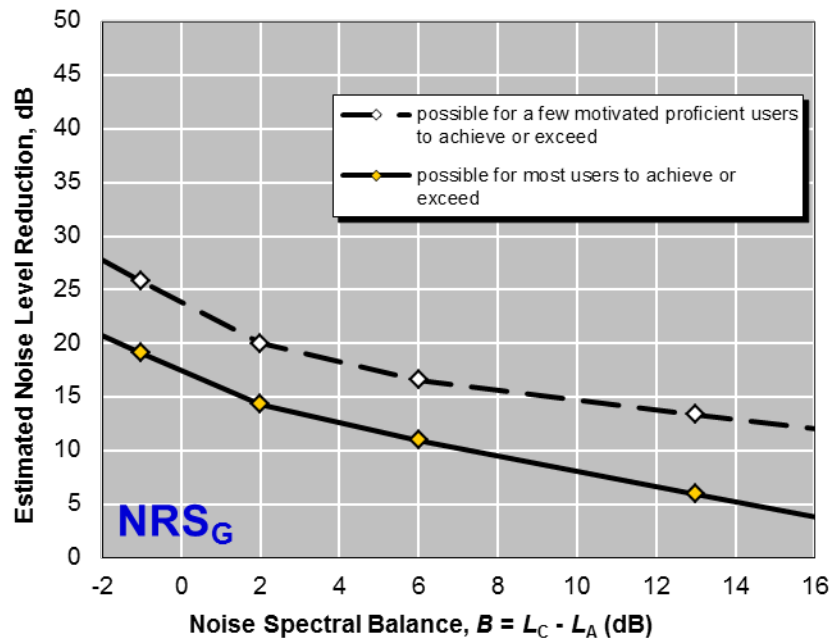


Figure 6. NRS_G results for OTTO Hurricane headset with Invisio V60 and Sonic Defenders EP4 earplugs, electronics off filters OPEN

NRS_A is the simplest method and can be used by subtracting the value from the measured A-weighted noise level to estimate the level of sound at the ear under the hearing protector. This method offers several advantages over the well-known NRR. The NRR was developed to be subtracted from the C-weighted noise exposure, with a 7-dB adjustment that must be applied prior to subtracting it from A-weighted exposure values. C-weighted exposure values are often not known, and therefore the rating for subtraction from A-weighted exposures with the NRS_A eliminates these problems with the NRR. Another advantage of the NRS_A is that it calculates two levels of protection to indicate the range of performance that was achieved (Figures 7-8); this range reflects both the variation across the subjects in the test panel providing insight into how hard/easy the device may be to fit, as well as variation in noise level reduction with the noise spectrum in which the device is used.¹² The majority of users (80%) will achieve the performance specified by the lower value in the range, with only the most motivated proficient users (20%) able to achieve the higher value. A narrow range indicates the hearing protection device provided a more stable and predictable level of protection. The NRS_A range for the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs was approximately 6 dB for both the open and closed filter configuration. The values for the closed and open filter was 21.8 and 14.55 dB of attenuation on the lower end (80%) and increased to 27.6 and 21.8 dB of attenuation on the higher end (20%) respectively. When the methods described in ANSI S12.68 (octave band method, NRS_G , and NRS_A) cannot be used, the use of the NRR (mean-2SD) is acceptable with the use of appropriate deratings.

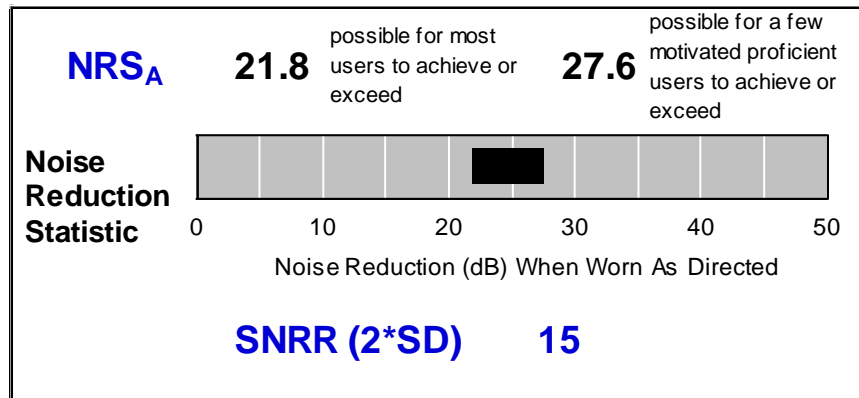


Figure 7. NRS_A results for OTTO Hurricane headset with Invisio V60 and Sonic Defenders EP4 earplugs, electronics off filters CLOSED

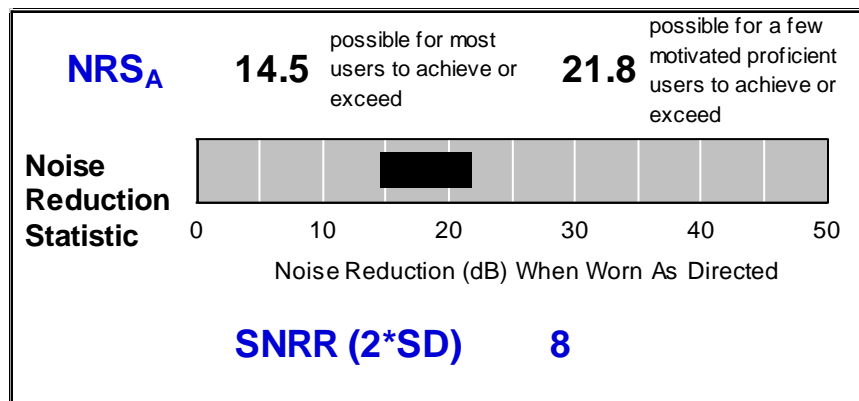


Figure 8. NRS_A results for OTTO Hurricane headset with Invisio V60 and Sonic Defenders EP4 earplugs, electronics off filters OPEN

3.3 Auditory Localization

Localization performance was measured for 8 paid volunteer subjects; 4 male and 4 female subjects ranging from 18 to 32 years of age. All subjects had bilateral hearing threshold levels less than or equal to 15 dB from 125 to 8000 Hz. These 8 subjects were a subset of the 20 subjects used for continuous noise attenuation measurements.

All measurements were collected in ALF (Figure 9) at WPAFB. The aluminum-frame geodesic sphere was 14 feet in diameter with 4.5 inch loudspeakers, each of which was equipped with four light-emitting diodes (LEDs) located at each of the 277 vertices on its inside surface. The ALF apparatus was housed within an anechoic chamber. The subject stood on a platform in the center of the sphere. The location of the platform had the potential to distort the signals from the speakers located directly below the subject, therefore only 237 loudspeakers, evenly distributed, above -45° elevation, were used in this study. The distance between speakers ranged roughly between 12° and 15°.



Figure 9. Auditory Localization Facility (ALF) at WPAFB

Subjects registered their responses with an Intersense IS-900 tracking system (Figure 10). The IS-900 used inertial-ultrasonic hybrid tracking technology to provide precise position and orientation information. The tracking system included a head tracker coupled with a response wand. The head tracker was mounted on the subjects' head to provide tracking data on the X, Y, and Z coordinate location of the head, as well as the yaw, pitch and roll during the duration of each trial. The head tracker also assisted the subject in aligning his/her head to the 0° azimuth, 0° elevation speaker location to begin each trial. The response wand was equipped with a joystick and five buttons which could be programmed for various purposes depending on the task. For this study, the subjects were required to press a single button while pointing the wand at their desired response location.



Figure 10. Intersense IS-900 tracking system

The stimuli were presented to the subjects in two different conditions. In one condition, the stimulus was a 250-ms burst of broadband (200 Hz - 16 kHz) pink noise. This duration was chosen in order to reduce the possibility that a subject would initiate a head

movement during the stimulus presentation. Such a movement would provide dynamic localization cues, which would result in improved performance. In addition many real world sounds encountered by the user are likely to be short duration (e.g. weapons fire, explosions). In another condition, a broadband (200 Hz - 16 kHz) pink noise was presented continuously until a localization response was made. This allowed subjects to make use of dynamic localization cues and move their heads during stimulus presentation to orient to the sound.

The test configurations were the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 closed, the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 open, and a control configuration labeled as “Open,” (unoccluded ear). The experiment was coded and executed using the MATLAB programming language by Mathworks™. For each configuration the subject fit him/herself with the appropriate device according to the directions provided by the manufacturer. The fit was verified by the experimenter, the hear-thru mode was activated, and the unity gain was set. The experimenter then directed the subject from the control room, where the fitting took place, into ALF. Once inside the sphere, the standing subject was raised or lowered by adjusting the height of the platform to ensure the subject’s head was in the center of the sphere.

To start each trial the subject aligned his/her head to a loudspeaker located directly in front of them (0° azimuth, 0° elevation) and pressed a button on the response wand. A stimulus was presented randomly from one of the 237 speakers in the sphere. The stimulus was either a 250 ms burst of pink noise or a presentation of continuous pink noise. The subject would then locate and select the target speaker by pointing at it with the wand and clicking the response button to enter his/her selection. The LEDs on the speakers were tracked to the wand’s movement so the subject could verify the location of his/her response. After a response was recorded, the LEDs of the target speaker were activated to give the subject feedback on his/her performance.

Each of the 8 subjects completed 320 trials in the burst noise condition and 64 trials under the continuous noise condition for each device configuration and one control condition in which no device was worn. Both burst and continuous stimuli could be presented in a single block of trials. All stimuli were presented at 65dB.

Two metrics of particular interest were percentage of angular errors > 45°, and percentage of front-back reversals. Both of these metrics were obtained from the same data set. Table 3 and Figure 11 show the percentage of mean angular errors that were >45° with each hearing protector for the burst and continuous noise conditions. Angular error is the difference between the actual target location and the subject’s response location as measured by the distance between the two points along the surface of the sphere. The rationale behind this measurement was its operational relevance. In general, we assume that if an operator’s attention can be directed to within 45°, he/she will then be able to use other sensory information, especially vision, to acquire the target. Subject data was collected with an “open” ear configuration (unoccluded ear) in order to serve as a reference point for determining how wearing a hearing protection and communication device affects localization performance. Subjects had errors >45° 1.4% of the time in the

burst noise condition and 0.4% in the continuous noise condition when no device was worn. The data demonstrated that localization performance was degraded significantly when the OTTO Hurricane with EP4 closed was worn for the burst noise condition, with errors $>45^\circ$ 22% of the time. When the filters were worn in the open condition, there was still a significant reduction in performance for the burst noise condition, with errors $>45^\circ$ 18.8% of the time. Localization performances with this particular metric in the continuous noise conditions were not significantly affected by device use.

Table 3. Percentage of mean angular errors $> 45^\circ$ for burst and continuous noise conditions

Device	Burst (%)	Continuous (%)
Open Ear	1.4	0.4
OTTO (V60/EP4 Closed)	22.0	2.3
OTTO (V60/EP4 Open)	18.8	4.1

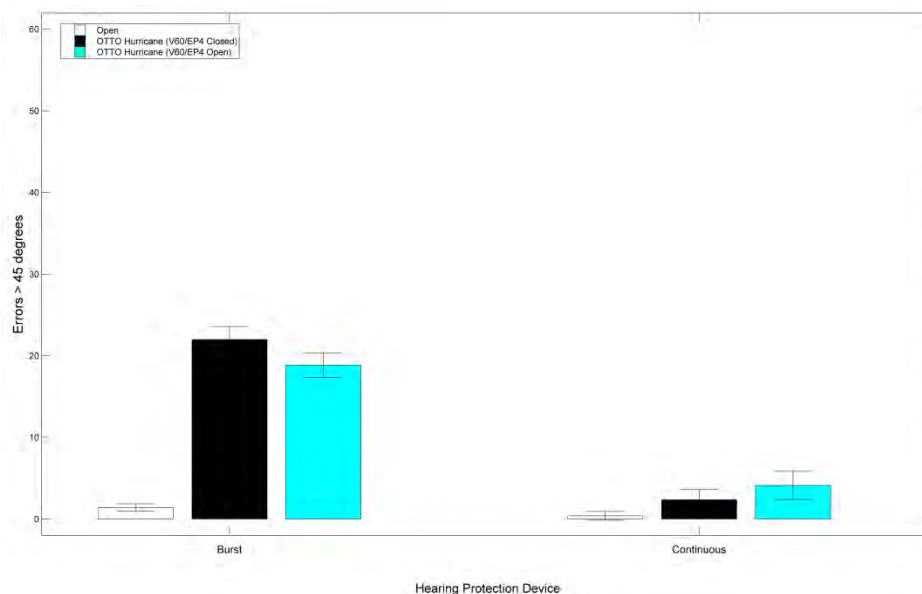


Figure 11. Percentage of mean angular errors $> 45^\circ$ for burst and continuous noise conditions

Front-back reversals occur when a subject is unable to determine whether a sound is in front of them or behind them. The percentage of front-back reversals is displayed in Table 4 and Figure 12. As previously stated, the percentages for front-back reversal are compiled from the same measurement as the errors $>45^\circ$; these metrics are two different ways to interpret the same data set. In the "Open" configuration the subjects had front-back confusions only 4.0% of the time in the burst noise condition and 0.9% in the continuous noise condition. The data for front-back reversals demonstrated that localization performance for burst noise was degraded when the OTTO Hurricane with EP4 (closed or open) was worn for the burst noise condition. The number of front-back confusions increased to 19.7% and 16.6% for the closed and open filter configurations. However, analogous to the data from angular errors $>45^\circ$, localization performances with this particular metric in the continuous noise conditions were not significantly affected by device.

Table 4. Percentage of front-back reversals for the burst and continuous noise condition

Device	Burst (%)	Continuous (%)
Open Ear	3.9	1
OTTO (V60/EP4 Closed)	19.7	1.4
OTTO (V60/EP4 Open)	16.6	1.2

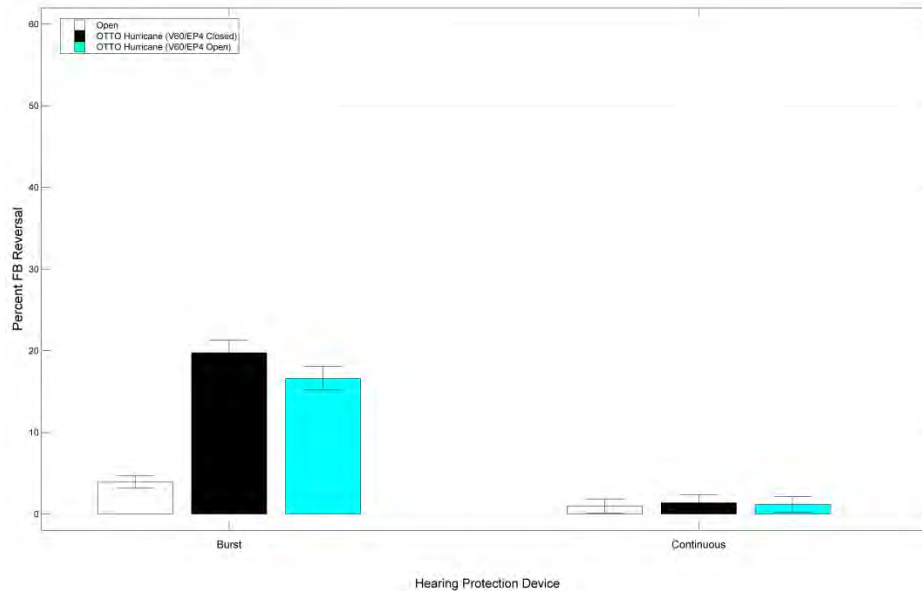


Figure 12. Percentage of front-back reversals for the burst and continuous noise condition

3.4 Aurally Guided Visual Search

Data were collected in an aurally guided visual search task using the same eight subjects that participated in localization measurements. All measurements were collected in ALF at WPAFB. The facility design and setup, as well as the subject fitting procedure and setup procedure once inside facility, are described in detail in the localization section above.

As previously indicated, a cluster of four LEDs was mounted at the center of each speaker in ALF. Subjects were tasked to complete an aurally guided visual search task where they identified a visual target in the presence of 50 visual distracters at randomly selected positions around the sphere. For this task, the target stimulus was a cluster of LEDs in which either two or four LEDs were illuminated. The distracter stimuli were clusters of LEDs with either one or three illuminated LEDs. In addition, a 250 ms burst of broadband (200 Hz - 16 kHz) pink noise was played from the speaker at the target location at a predetermined sound level. The time required for the subject to find and identify the target was measured as a function of the noise-burst SPL with the communication device, with the “Open” configuration (unoccluded ear) as a reference.

To start each trial the subject aligned his/her head with a designated loudspeaker located directly in front of them (defined as 0° azimuth, 0° elevation) and pressed the trigger button on the underside of the response wand. At this point, 50 distracter stimuli were illuminated along with the one target stimulus. The subjects' task was to quickly locate the target stimulus and identify whether two or four LEDs were illuminated at the target location by pressing a response button on the top of the ALF response wand. After the subject recorded his/her response, he/she would realign to the front speaker to begin the next trial.

The configurations were the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 closed, the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 open, and a control condition labeled as "Open," (unoccluded ear). Each of the 8 subjects completed 180 trials per configuration, with 60 trials at 15, 40, and 70 dB. In addition, each subject completed 60 trials in an unoccluded (open) visual only condition where the subject was given no auditory clue and forced to visually search for the target. Levels were selected that spanned a range from quiet to easily audible (not to exceed 85 dB SPL at the eardrum).

Previous results from our lab have shown a large reduction in the time it takes to acquire a visual target when a sound that is easily detectable and localizable was played from the target location, relative to a visual search with no aural guide. A reference point for the visual only search was added to Figure 13. The subjects took at least 4 more seconds to find the target when wearing the OTTO Hurricane (filters open or closed) in comparison to the open-ear condition regardless of the generated noise level. The averaged response times decreased with increasing presentation level as the auditory stimuli become more audible and localizable (Figure 13). However, even at the maximum presentation level the performance was still degraded when wearing the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs in comparison to the open-ear condition.

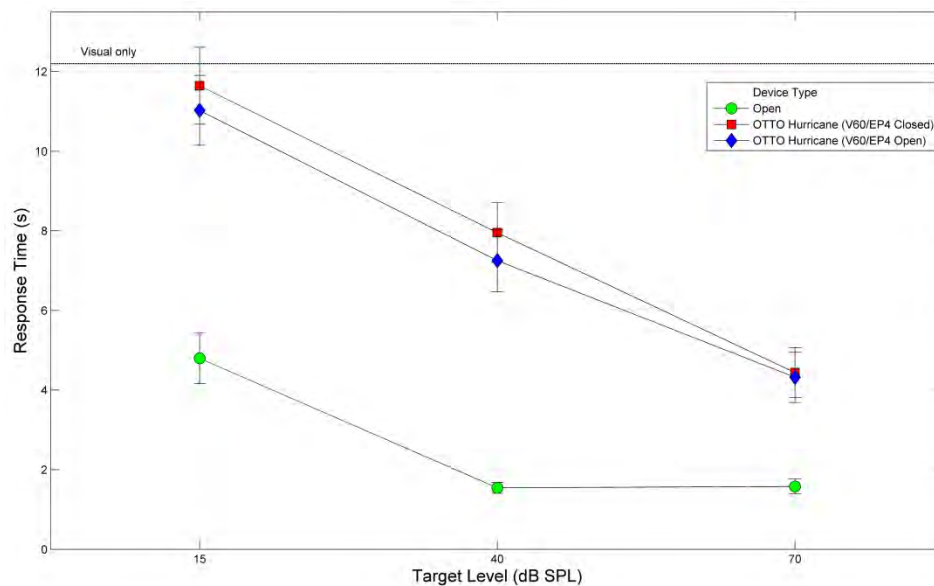


Figure 13. Average response time for an aurally guided visual search task

3.5 VOCRES – Speech Intelligibility

The AFRL VOice Communication Research and Evaluation System (VOCRES) facility was used to measure the speech intelligibility performance of the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs. VOCRES was designed to evaluate voice communication effectiveness in operationally-realistic acoustic environments. The facility consisted of a programmable, high-power sound system housed in a large reverberant chamber, capable of generating high-level (130 dB sound pressure level) noise emulating acoustic environments in operational situations. Ten operator workstations were positioned in the facility (Figure 14), each equipped with a touch-screen display and communication system capable of replicating end-to-end military communication chains (i.e., intercoms, oxygen systems, headsets, microphones, and helmets). In this way, full communication systems, as well as individual system components, may be evaluated under operational conditions to determine the impact these systems might have on speech intelligibility and communication effectiveness.



Figure 14. AFRL's VOCRES facility used to measure speech intelligibility performance

This facility allowed the ambient noise level to be varied by presenting pink noise via a large amplified sound system. Participants were monitored by the experimenter using a closed-circuit camera and monitor system. Verbal instructions regarding experimental procedures were provided to participants. Stimuli were presented by live talker. Cueing of target words for the talker and recording of listener responses were both accomplished via a custom MatLab 7.0 application. A laptop computer with a graphical user interface (GUI) was utilized for subject response. The talker and listeners had individual computers at their respective work stations.

Measurements were conducted in accordance with ANSI S3.2³ with the exception of the number of subjects. A limited number of assets reduced the number of subjects from five talkers and five listeners to four talkers and four listeners. The Modified Rhyme Test (MRT) was selected for the test material. The MRT consisted of 50 six-word lists of rhyming monosyllabic English words. Measurements for the device was collected in 65,

85, and 105 dB overall sound pressure level (OASPL). The 105 dB condition was not attempted for the filter open condition to ensure subject safety. The talker and listeners were in the same noise environment. The goal was to quantify the ability of trained listeners to correctly identify target words transmitted by a trained talker using the combination of Multi-Band Intra/Inter Team Radio (MBITR) and the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs.

For data collection, each presentation of a MRT list consisted of one talker position and three listener positions. Each talker completed three MRT lists in each noise condition. During the experimental task, the talker was presented with the stimulus on the computer screen (“You will mark MRT word, please”). The talker then communicated the phrase to the three listeners via the MBITR radio and headset combination. Listeners selected the word heard by using a pen to click on the correct word from a list of six words on the tablet screen. Responses were recorded and an average score was calculated. An example of the MRT format for the talker and listener stations is provided in Figure 15.

1.	<table><tr><td>Went</td><td>Sent</td><td>Bent</td></tr><tr><td>Dent</td><td>Tent</td><td>Rent</td></tr></table>	Went	Sent	Bent	Dent	Tent	Rent
Went	Sent	Bent					
Dent	Tent	Rent					
Number 1, you will mark WENT please.							
Number 2, you will mark HOLD please.	2.						
Number 3, you will mark PAT please.	<table><tr><td>Sold</td><td>Cold</td><td>Told</td></tr><tr><td>Fold</td><td>Hold</td><td>Gold</td></tr></table>	Sold	Cold	Told	Fold	Hold	Gold
Sold	Cold	Told					
Fold	Hold	Gold					
.							
3.	<table><tr><td>Pan</td><td>Pad</td><td>Pat</td></tr><tr><td>Path</td><td>Pack</td><td>Pass</td></tr></table>	Pan	Pad	Pat	Path	Pack	Pass
Pan	Pad	Pat					
Path	Pack	Pass					
.							

Figure 15. Examples of the talker (left) and listener (right) ensembles

Speech intelligibility results were combined for all subjects for each noise level. The subjects’ scores were adjusted for guessing as described in ANSI S3.2.³ An overall average was then calculated for all subjects. The speech intelligibility scores for the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs are presented in Table 5. The calculated scores in the 65 and 85 dB noise environments were $\geq 80\%$ for both the open and closed filter conditions while the scores in the 105 dB noise environment dropped to 65% for the closed filter condition. No measurements were collected in the 105 dB noise environment with the filters of the earplugs in the open configuration for subject safety.

$$Score = 2(R - \frac{W}{n-1})$$

Where:

<i>Score</i>	=	Percent Correct (Adjusted For Guessing)
<i>R</i>	=	Number Correct
<i>W</i>	=	Number Incorrect
<i>n</i>	=	6 (number of choices available to listener)

Table 5. Speech Intelligibility Scores with OTTO Hurricane headset with Invisio V60 and Sonic Defenders EP4 earplugs

	OTTO Hurricane Closed	OTTO Hurricane Open
Noise Level (dB)	% Correct	% Correct
65 dB	89.8	92.5
85 dB	82.3	86.5
105 dB	65.1	Not Tested *

4.0 DISCUSSION

All hearing protection devices can and should be assessed in multiple ways to describe the performance of the device and the effects on an operator's ability to perform the mission. Subjective and objective measurements can be conducted to characterize a device's noise attenuation performance as well as any effect on situational awareness that may result. Passive attenuation in continuous noise environments, auditory localization capabilities, and speech intelligibility were all assessed for the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs.

5.1 Localization and Detection versus Attenuation

Military personnel are exposed to various noise environments depending on their mission: continuous and/or impulsive, predictable and unpredictable. Also, dependent on their mission, the metrics measuring the performance of the hearing protection device may carry different weighting. For some missions, auditory localization may be more important than noise attenuation while for other missions attenuation may be more important than localization. These different weightings should be considered by those who are selecting hearing protection and communication devices for a particular mission or group of users. It is critical to consider the environment of the end user, and evaluate the pros and cons for each assessment area independently for an informed decision. The end user must be aware that their ability to localize environmental sounds will not be as good as the unoccluded ear when using the OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs.

5.2 Speech Intelligibility

The OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs performed in the acceptable range for speech intelligibility performance at noise levels of 65 and 85 dB, but did not perform in the acceptable range at the level of 105 dB. A score of 80% or greater would be considered acceptable according to current military standards¹⁶. It is advisable to consider the noise environment of the mission when considering the use of this product.

5.0 CONCLUSION

The OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs was evaluated for: continuous noise attenuation, auditory localization, and speech intelligibility. The OTTO Hurricane with Invisio V60 and Sonic Defenders EP4 earplugs with filters opened and closed caused significant impairments to localization performance versus the open ear condition for noise burst sounds. However, the combination of devices did meet acceptable speech intelligibility scores for the current military standards at 65 dB and 85 dB. In the higher noise environments, 105 dB, speech intelligibility scores fell below the acceptable performance level. The results of the hearing protector and communication device performance assessment may provide insight into the development of design criteria for the next generation of devices, and assist in choosing the best device or combination of devices for a given operational mission.

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